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NATURAL CONTROL OF THE CITRUS MEALYBUG IN FLORIDA.

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INTRODUCTION.

The citrus mealybug (*Pseudococcus citri* Risso) is widely distributed in Florida and the Gulf States and infests the several varieties of citrus and various other plants cultivated in this region. While it sometimes causes a premature drop of citrus fruit, in most instances more injury is wrought by the sooty mold which develops luxuriantly upon the fruit where the insects are feeding. On the whole, however, the mealybug is considered a pest of secondary importance in Florida, as it usually does not appear in sufficient numbers to arouse the apprehension of the grower. In California, on the contrary, it is looked upon as one of the most serious insect enemies of citrus.[1] The object of the present paper is to show why, in Florida, it is usually unimportant and to point out that a knowledge of its natural enemies is of direct economic value to the citrus grower.

CITRUS CONDITIONS IN FLORIDA.

In Florida, perhaps more than in any other citrus region of the world, are environmental factors conducive to the control of injuri-

[1] Woglum, R. S., and Neuls, J. D. The common mealybug and its control in California. U. S. Dept. Agr. Farmers' Bul. 862, p. 11. 1917.

ous insects by entomogenous fungi. It is favored by a rainy season, more or less well defined, lasting from June to September, which correlates reasonably well with the growing season of the trees. The more important insect pests in a large measure are dependent upon the new growth or "flush" of the citrus trees for their successful development and reproduction. Hence the period of maximum abundance of these insects, which naturally coincides with the period of greatest food supply, at the same time coincides with the rainy season. This is fortunate, for the environmental factors which are normally present in the summer during periods of greatest insect injury are very favorable for the development of the various species of fungi that prey upon and destroy the injurious insects.

These entomogenous fungi are worth millions of dollars to the citrus industry. Owing to their excellent work, oranges and grapefruit are grown at a profit in many parts of the State where no money whatsoever is spent on artificial remedial measures. It should not be inferred that spraying to control citrus pests is not advised. A greater profit can be enjoyed when sprays are employed judiciously, particularly if they are utilized in a way to supplement the work of the fungi, but citrus fruits can be grown at a profit in the absence of any artificial measures, a condition probably not possible, for instance, in the apple industry. The inestimable value of the entomogenous fungi to the citrus grower of Florida is thus evident.

If it were possible to eliminate these organisms from the State and at the same time permit the injurious insects which they attack to remain uncontrolled by artificial measures, the growing of oranges and grapefruit would be an extremely hazardous occupation in which the monetary rewards would be negligible or absent. Other things being equal, it is estimated that in the absence of these fungi the annual citrus crop would be reduced by at least 50 per cent, so great would be the injury wrought by scale insects and the white fly.

These statements are based upon the experience of the Federal agents, the State specialists, and the growers themselves, who, while permitting other factors to function normally, have at times inadvertently or otherwise eliminated in small areas, by sprays of Bordeaux mixture, the entomogenous fungi, which are killed effectively and completely by this fungicide. They have found that trees sprayed with it afford excellent feeding places for the insect pests, and that as the development and reproduction of the latter are unimpeded by the entomogenous fungi, they multiply prolifically, causing heavy defoliation, a very high percentage of fruit drop, and unsightly unmarketable fruit, and even threaten the very life of the trees.

INSECT ENEMIES OF THE MEALYBUG, AND INSECTS ASSOCIATED WITH THE MEALYBUGS AND SOMETIMES CONSIDERED AS BENEFICIAL.

During the past two summers, 1920 and 1921, three insects have been found associated with mealybugs: *Pyroderces rileyi* Wlsm.,[2] *Laetilia coccidivora* Comst.,[2] and a species of Chrysoplatycerus.[3]

The larva of the tineid moth *Pyroderces rileyi*, known as the pink cornworm or scavenger bollworm, is conspicuous in mealybug clusters, occurring abundantly between clustering grapefruit, particularly if dead leaves are pinioned in the cluster. It is perhaps the most common of all insects frequenting mealybug clusters, and many growers are of the opinion that it feeds upon the mealybug. The larvæ are deep pink or "wine red" (Busck[4]) in color, about three-eighths of an inch long, and more or less cylindrical in form. Just back of the head a rectangular, almost black area is to be noted, which, though common to other lepidopterous larvæ, serves at once to distinguish the common Florida form from other larvæ occasionally found in similar situations. The insect is without doubt a scavenger, playing no economic rôle as far as the mealybug is concerned. Busck[4] reported it as a trash feeder. The writer, unaware of this or similar publications, performed some experiments to determine its relationship to the mealybug. A few larvæ brought into the laboratory were confined with live mealybugs in a glass vial for several days, but none of the mealybugs were eaten. On the other hand, an old dead leaf found sandwiched between two grapefruit, covered with the larvæ, was brought into the laboratory and confined in a pill box in a moist chamber. On this the larvæ grew to maturity in the complete absence of mealybugs.

The second insect, the pyralid moth, *Laetilia coccidivora*, is much less common than *Pyroderces rileyi*, but, like it, occurs in the larva stage associated with mealybugs. The writer performed no experiments with this insect, but it is looked upon generally as predacious in habit, feeding upon the mealybugs. In the Winter Haven grove, where the observations of the past season were made, however, it was not abundant, and among the thousands of mealybugs that were collected for experimental purposes only 12 of these larvæ were observed. The full-grown larva is somewhat larger than that of *Pyroderces rileyi* and is grayish green in color. It forms a silken web, beneath which it lives and feeds.

The third insect, now apparently in Florida, is a chalcid, an unknown species of Chrysoplatycerus. The specimens submitted for

[2] Determined by Carl Heinrich, of the Bureau of Entomology.

[3] The writer is indebted to A. B. Gahan, of the Bureau of Entomology, for the generic identification of this insect and for the information regarding *C. splendens* Howard.

[4] Busck, August. The pink bollworm, *Pectinophora gossypiella*. *In* Jour. Agr. Res., v. 9, no. 10, p. 362, 366, 1917.

determination were immature, and a specific determination was therefore impossible. *C. splendens* Howard, a similar species, is recorded as bred from mealybugs in California, but according to Gahan it was regarded by Timberlake as a secondary parasite. No evidence was obtained that the insect bred from mealybugs in Florida was a secondary parasite, and it is to be inferred from Smith and Armitage[5] that they do not so regard the California form; but as hyperparasitism was not suspected, no particular observations were made to determine this point. Attention was first attracted to certain mealybugs whose bodies were hard and brittle and dark colored, thus contrasting sharply in appearance and characteristics with the bodies of healthy individuals. Upon breaking the body wall of such mealybugs one of the above-mentioned insects was discovered within. Others were subsequently bred out in a normal manner; and although no record of the number was preserved, there were in all not over a dozen, and for that reason these insects can not be looked upon as a considerable factor in the natural control of the mealybug, even if they should prove to be parasitic.

THE FUNGOUS PARASITE ENTOMOPHTHORA FUMOSA, N. SP.

In addition to the insects mentioned, which were, of course, studied more or less incidentally, a fungus was discovered which is unquestionably the chief factor in the natural control of the citrus mealybug in Florida. This parasite was first observed in Florida in 1920 in Orlando, but it had been previously sent to the writer by T. H. Jones, of Baton Rouge, La., where it was collected in 1917 on the citrus mealybug on fig. Mr. Jones subsequently (1920) sent in the same fungus on *Phenacoccus* sp. on Hibiscus from Baton Rouge. While first found in Florida in Orlando, it was later discovered in various regions of the State, extending from Clearwater to Fort Pierce, and there is every reason to believe that it is distributed generally throughout the citrus belt.

The organism in question belongs to the family Entomophthorales, most members of which are entomogenous. Both in appearance and relationship it is entirely unlike the other fungi which have been recorded as occurring upon citrus pests in Florida. A somewhat similar form was described by the writer[6] on the sugar-cane mealybug (*Pseudococcus calceolariae* Mask.) in Hawaii, and what seems to be a very closely related species, *Empusa lecanii*, has been observed on *Coccus viridis* (Green), a coffee pest in Java, although it is impossible from either the text or illustrations to determine definitely

[5] Smith, Harry S., and Armitage, H. M. Biological control of mealybugs in California. Calif. Sta. Dept. Agr., Monthly Bul., v. 9, no. 4, p. 109, 1920.

[6] Speare, A. T. Fungi parasitic upon insects injurious to sugar cane. Hawaiian Sugar Planters' Association, Exp. Sta. Bul. 12, Path. and Physiol. Ser., p. 14, 1912. Honolulu.

whether or not the two are identical. Inasmuch, however, as no resting spores were observed on the Java material, and as the conidia seem unlike those of the Florida form, the writer has chosen to regard the latter as a new species. Zimmerman,[7] in discussing the Java form, described very well the spherical hyphal bodies. It is interesting to note that he observed four nuclei in these cells, and that the writer subsequently found the same number (Pl. I, 10) in the corresponding vegetative stage of the present organism. The conidia were described as pear-shaped, approximately 18 microns long and 9 to 10 microns wide. A dark-colored conidial membrane is also mentioned. Johnston[8] reported a mealybug Entomophthora from Porto Rico which he doubtfully referred to *E. fresenii*. He observed no resting spores, however, and apparently regarded the assignment of this form to *E. fresenii* as tentative. It may be identical with the one herein considered.

As a group the various species of Entomophthora are perhaps the most important natural control agents of insects known among the fungi. Species have been recorded on members of the following insect orders: Diptera, Lepidoptera, Orthoptera, Hemiptera, Coleoptera, Hymenoptera, Neuroptera, Thysanoptera; they have also been recorded on the Arachnida, and the writer has observed a species of the *Grylli* type upon a large myriapod in the vicinity of Washington, D. C. Many of the attacked insects are injurious, as, for example, the brown-tail moth, *Euproctis chrysorrhoea* L., which is destroyed in vast numbers, and in fact this insect is to-day in a virtual state of control in the United States, due largely to the work of *Entomophthora aulicae*.

The citrus mealybug Entomophthora ranks as high as the brown-tail moth fungus as a control agent. That it has passed unobserved—that its work has not been before realized—is due to a lack of knowledge. It has probably been present in Florida for years, exacting an enormous toll of mealybugs year after year, and bringing about, during many seasons, the virtual control of this insect. Such a lack of knowledge doubtless has caused, through misdirected efforts, the waste of much money among the citrus growers in Florida.

While it is sometimes difficult to separate the various species of this genus taxonomically, in the present instance it was not particularly so, as the fungus can not possibly be confused with any known species except the poorly described *E. lecanii*. It possesses resting spores unlike those of any known form, and its conidia are

[7] Konigsberger, J. C., and Zimmerman, A. De dierlijke vijanden der koffiecultuur op Java. Deel II. Meded. 'Slands Plantentuin, no. 44, p. 16. 1901.

[8] Johnston, J. R. The entomogenous fungi of Porto Rico. Board Comm. Agr. Bul. 10, Rio Piedras, P. R., p. 21. 1915.

likewise quite distinct. In many respects the ubiquitous *E. fresenii* as well as *E. lageniformis*, both aphid parasites, are more nearly allied to it than other known species. The similarity is due to the smoke-colored hyphæ and conidia, the peculiar secondary conidia, and the dark resting spores, characters present in all of the forms which were regarded by Thaxter as sufficiently distinct from the typical Entomophthora, such as *E. aulicae*, to justify a group of subgeneric (*Triplosporium*) value.

DESCRIPTION.

Entomophthora fumosa, n. sp.

Conidia typically more or less fusiform, 16 to 20 microns by 8 to 10 microns, distinctly smoke-colored, tapering rather abruptly toward both the base and apex, occasionally elliptical. Apex sharply rounded, base or papilla weak but clearly visible; conidiophores simple, smoke-colored, slender, arising directly from spherical yellowish hyphal bodies. Secondary conidia elliptical, small, 4 by 8 microns, rather thick-walled, without papillæ, arising on 1 to 5 slender, capillarylike conidiophores from each primary conidium. Resting spores (zygospores?) apparently arising from conjugation of hyphal bodies, spherical, opaquely black, 15 microns in diameter, invariably provided with a hyaline protuberance or appendage. When crushed, black exospore cracks, revealing internal, hyaline, spherical, thick-walled spore. Host attached to substratum by insertion of proboscis.

On *Pseudococcus citri* Risso on *Citrus* spp., Florida; on *Pseudococcus citri* on *Ficus* sp., Louisiana; on *Phenacoccus* sp. on *Hibiscus* sp., Louisiana.

MICROSCOPIC CHARACTERS.

It is a relatively simple matter with a microscope to recognize this disease very early in its development, because the organism which causes it is large and possesses unique characters. Insects which are suspected of having the disease are crushed in water and mounted on a slide. If the organism is present, bodies such as those represented in Plate I, 16, will be observed. Such bodies are always evident if a milky white liquid emerges when the body is crushed, and often they can be detected, though in lesser numbers, before the blood appears white. They have been termed "hyphal bodies" and, while somewhat variable, in so far as shape and appearance are concerned, in the different species of the genus, in the species under consideration they are perfectly spherical, very thin walled, and are filled with a very finely granular protoplasmic content. The wall which surrounds these bodies is exceedingly thin and plastic, as shown by the fact that when pressure is applied unequally upon their surfaces the

wall bulges out in the direction of least resistance, with the result that asymmetrical, egg-shaped, or even dumb-bell-shaped bodies are formed. They represent the vegetative stage of the fungus, the stage in which the parasite grows at the expense of its host. Such bodies live, so far as can be determined, primarily in the blood, absorbing nourishment therefrom, but after having absorbed the blood, or at least after all of the body fluids have disappeared in diseased mealybugs, other tissues break down and evidently furnish additional food. As they grow they reproduce rapidly by a budding-off process. While at first they apparently impede the blood circulation slightly, they later fill up every nook and crevice of the body cavity and must therefore nearly inhibit it. Later the muscles and all other soft tissues are destroyed, leaving only the heavily chitinized structures, until at last the interior of the insect's body is completely and solidly filled. It is at this stage of development, when all liquid matter has been absorbed, that the body cuts like a piece of cheese. This condition marks the end of the vegetative stage.

All subsequent development of the parasite which takes place after the insect is dead is reproductive. Two types of reproductive bodies are formed, conidia and resting spores, the type depending upon factors that are only in part understood. In certain other species they may be formed simultaneously in and on the same individual, though in the present instance resting spores and conidia are not associated in the same specimen. Whichever reproductive body is formed, however, they both arise from the hyphal bodies, which obviously must behave differently in each instance.

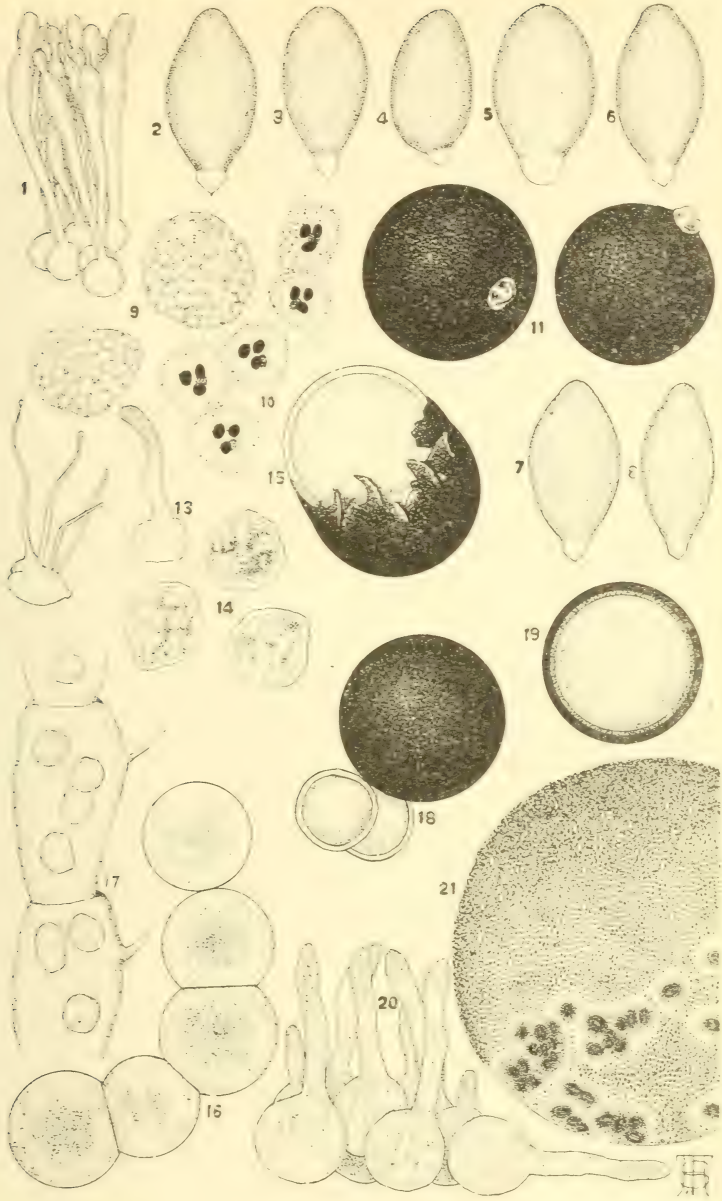
When conidia are to be produced the hyphal bodies send out simple "germ tubes" in the manner shown in Plate I, 20, which bore through the body wall of the host into the open air. Thousands of hyphal bodies produce as many germ tubes, and the latter on the outer surface of the insect's body, together with the conidia which are formed at their tips, cause the slate-gray colored wool-like appearance mentioned below. They stand out from the insect's body in much the same manner as the fascicles of hairs extend out from the body of a hairbrush. They swell up at their tips (Pl. I, 1) and into the swollen portion flows the entire protoplasmic content of the hyphal body and germ tube. By a process which is characteristic of this group of fungi, the swollen portions are cut off from the germ tube by transverse walls, and the resulting fusiform elliptical conidium is literally shot off from the germ tubes. The force by which this is accomplished is considerable, because the conidia are thrown to a distance of 5 or more millimeters. In some species of Entomophthora the conidia are thrown nearly an inch away from the body of the infected host. This phenomenon was observed several times

in connection with *E. fumosa* in the field. When at the proper stage of development, and when touched with a pair of forceps, a minute dustlike cloud, similar to that which arises when puffballs are disturbed, arose from mealybugs that were being collected for laboratory experiments. This cloud was, of course, due to the thousands of conidia which were discharged simultaneously when the body was touched with the forceps. Without such a stimulus the conidia are discharged singly or in very small numbers and are not visible to the naked eye. In *E. fumosa*, however, the force of the discharge, compared with that of many other species, is relatively weak, a fact substantiated by the somewhat slender conidiophores and the comparative weak conidial papillæ.

It is believed that this method of spore discharge is of great value in perpetuating the fungus, in that it aids appreciably in the dissemination of the spores. Citrus mealybugs, while not exactly sedentary insects, are more or less gregarious in their habits and in nature crawl about over one another and huddle together in bunches; hence the value of such a method of spore discharge is not so great as it would be, for example, in a parasite of less gregarious insects, or of those which are more or less peripatetic in their habits.

The conidia or spores of this fungus are probably spread from colony to colony in part by the process just described, in part by insects, particularly ants that frequent mealybug colonies, and in part by air currents, in contrast, in this last respect, to the Aschersonias, which apparently are distributed largely by rain water. While a certain amount of moisture is necessary for the best development of most fungi, a slight increase in humidity such as that which accompanies a heavy dew is sufficient to cause sporulation in the forms like *E. fumosa*, a fact repeatedly observed in Florida during the summer of 1921.

The second type of reproductive development, which results in bodies called resting spores, is totally unlike that noted above, and to one not familiar with the organism involved, the identity of these resting spores might well be obscure. When resting spores are formed there is no external growth whatever upon the insect's body. The spherical, smoke-colored resting spores, opaquely black at maturity, are formed internally directly from the hyphal bodies. They are extremely thick walled and in fact are provided with two walls, each of which is very thick, the outer of these, the exospore, alone containing the black pigment. It is somewhat indurated and cracks rather easily when pressure is applied, separating freely from the inner hyaline endospore (Pl. I, 15). While the germination of these bodies has not been observed, it is believed that they tide the fungus over periods of unfavorable conditions, such as occur, for example, during the winter season in Florida. As already



ENTOMOPHTHORA FUMOSA.

1, Group of conidiophores, showing conidia in various stages of formation, × 164. 2–8, Conidia, × 655. 9, Hyphal bodies, showing appearance when mounted in alcohol, × 655. 10, Hyphal bodies, showing nuclei, × 605. 11, Resting spores, × 655. 12, Germination of conidium, showing capillary-like germ tubes upon which secondary conidia are formed, × 332. 13, "Germinating" hyphal body, × 332. 14, Encysted hyphal bodies sometimes associated with resting spores, × 332. 15, Resting spore crushed, showing inner hyaline endospore, × 655. 16, Hyphal bodies as seen in a water mount. Taken from live mealybugs, × 655. 17, Hyphal bodies in leg of mealybug, × 164. 18, Resting spore with associated hyphal bodies, × 655. 19, Optical cross section of mature resting spore, × 655. 20, Group of germinating hyphal bodies, × 655. 21, Grapefruit, showing diseased mealybugs and discharged conidia of fungus on surface of the fruit. One-half natural size.

noted, this stage has been found much less abundantly in Florida than the conidial stage. This is perhaps due to the fact that the insects in which it occurs are invariably small in size, and usually hidden in bark crevices or other situations where their detection is difficult. The method of formation appears to be zygosporic, but a sexual process has never been actually observed. Specimens have occasionally been observed such as that drawn in Plate I, 18, but the exact nature of the association of the hyphal bodies to the resting spores has not been determined. The mature resting spore, however, is invariably provided with a hyaline papilla or protuberance which indicates that a sexual process somewhat like that described by Thaxter in *E. fresenii*, to which *E. fumosa* is in many other respects similar, has taken place. It is, in fact, difficult to explain the presence of this protuberance in any other way, for no known type of azygosporic formation produces such an appendage.

The nature of the factors which in the one instance cause the hyphal bodies to form conidia and in the other instance to form resting spores is incompletely understood. In certain species of Entomophthora both types are formed simultaneously in and on the same individual, but in *E. fumosa* they are not associated, diseased insects showing either conidia exclusively or resting spores exclusively. In *E. pseudococci* the writer[9] showed that zygospore formation could be readily induced by placing cultures containing "matured" hyphal bodies in darkness, and it seems probable that the same factor plays a part in the present instance, because, while the fungus was collected at various hours of the day, only mature resting spores were observed. None were seen in the process of formation during daylight hours. In certain other similar fungi, such as *Massospora cicadina*, the seasonal factor seems also to play a rather definite rôle. Resting spores of this form are produced late in the season only, after the conidial formation has ceased. In *E. fumosa* resting spores were in fact first observed at the time the mealybugs were becoming noticeably less numerous, though the small size and inconspicuousness of such infected insects may likewise have been factors preventing an earlier discovery.

As in many other species of the genus, the resting spores have never been observed to germinate. Failure to secure germination is apparently due to the fact that suitable artificial environmental conditions have never been supplied. In certain species, such as *E. pseudococci*, however, a germ tube arises from the resting spore which produces a conidium that is discharged in the usual manner; from analogy, therefore, it is believed that a similar process occurs in the species that have not yet been cultivated artificially.

[9] Speare, A. T. Op. cit.

SYMPTOMS OF THE DISEASE CAUSED BY E. FUMOSA.

The body of a healthy mealybug is more or less pliable, and, when depressed with the point of a penknife, will return to its original position when the pressure is withdrawn, much like a rubber ball. Mealybugs infected with this fungus in early stages of the disease to all outward appearance seem quite healthy, and in fact move about, though in a relatively sluggish manner. If, however, they are pressed with a penknife, the body wall ruptures very easily, permitting a droplet of milky white liquid to exude. When the body of a recently dead mealybug, which is also lifelike in appearance, is treated in this manner the depressed area remains sunken. Mealybugs were considered dead when upon being prodded with a needle no body or leg movement resulted. When the insect has been dead from 12 to 18 hours its body, although remaining lifelike, will appear more or less solid to the touch, and if considerable pressure is applied to the penknife it will cut like a piece of cheese. These are in brief the first symptoms of the disease observed by the writer which can be detected with a hand lens or naked eye. In 24 hours or so after the first of such symptoms have been observed, a change in external appearance takes place. Infected insects at this period and later may present dissimilar characteristics, and by the uninitiated the cause of death would probably be erroneously attributed to different organisms. In the one instance the infected insects appear to be enveloped in a dark slate-gray woolly covering. Such an appearance indicates that the conidia, the thin-walled reproductive bodies, formed externally and abundantly when conditions are favorable for their dissemination, are being produced. In the other instance the infected insects appear jet black in color, sometimes almost glistening, and the body surfaces are smooth, not woolly. The jet-black color is due to the enormous numbers of spherical black resting spores formed internally, the color of which is transmitted through the thin, intact, translucent body wall. Those presenting the first noted characteristics are by far the most abundant, whereas those in which resting spores are formed are rare, detected with difficulty, and occur invariably in young or at least very small individuals. In both instances the infected insects are attached rather lightly to the host by the insertion of their proboscides.

THE FUNGUS IN THE GROVE.

As noted, the fungus has been found in several isolated regions within the citrus belt and is assumed to have a general distribution. Most of the observations herein recorded were made either in Orlando or Winter Park in 1920, or in Orlando and Winter Haven in 1921. In Winter Haven one definite grove was visited at about weekly periods throughout the season.

The earliest seasonal record of the appearance of the fungus is June 13, 1921, when it was found at Winter Haven. While not abundant on this date there was considerable evidence to show that it had been present for some time previously. As the graph (Fig. 1) indicates, it became increasingly prevalent week by week up to August 8, when the last examination was made. At this date so widely scattered were the live mealybugs that a collection of representative specimens was made with difficulty.

Mealybugs of citrus in Florida are more prevalent upon grapefruit than upon orange. (See Fig. 2.) On such trees their favorite feeding location seems to be upon the fruit itself, or upon the fruit pedicels, where they form more or less well-defined colonies. At times they occur along the under side of large branches or limbs of

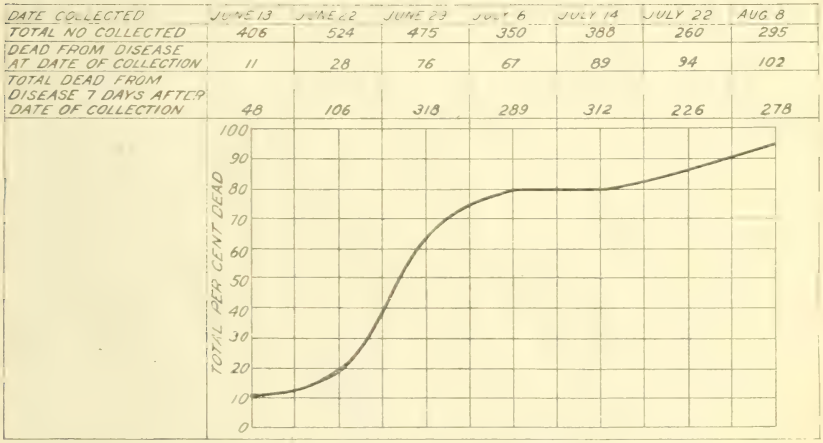


FIG. 1.—Data on collections of citrus mealybugs infected with *Entomophthora fumosa*.

the tree, although it is not known whether they are feeding or not. Mealybugs which frequent such situations are usually those which are ovipositing or about to oviposit. In most instances such insects are enveloped in a mass of wax, the excretion of which precedes or accompanies oviposition. Such a habit favors the spread of the mealybug, because the young crawlers hatching from the eggs will settle, in most instances, upon fresh fruit or twigs some distance away from the spot where the adults found their food. It is not to be inferred that mature females do not also lay eggs upon the fruit, but rather that young feeding individuals are not usually found upon the large branches. The habit of colonization, therefore, together with the white, grayish, or pinkish color of the healthy insects, renders their detection a simple matter.

The grove at Winter Haven was regarded as heavily infested. It was estimated on June 13 that 75 per cent of the trees were supporting five or more large colonies of the mealybug, that 20 per

cent bore one or two colonies, and that 5 per cent were free from the insects.

Infected mealybugs were first detected in this grove upon the fruit. Later in the season they were found nearly as abundantly upon the twigs and branches, where, however, they were detected with difficulty, owing to the neutral gray color of the fungus, which simulates rather closely the bark of the trees. Upon the grapefruit the dead bugs may occur singly, or more often in groups of four or five, huddled together as in life. Surrounding them upon the grapefruit a dark halo was often observed, which might easily be confused with the sooty mold that accompanies the insect. This appearance, however, is caused by masses of conidia which are discharged in enormous numbers and fall upon the grapefruit near or upon one another (Pl. I, 21). Dead insects upon the twigs and branches occur more often singly, most abundant in positions near the colony, but often from 5 to 10 feet away, and in such locations, owing to their small size, inconspicuous color, and position in the crevices of bark, are easily overlooked.

In studying this insect infestation during the period June 13 to August 8, one of the first facts which became apparent was the gradual disappearance, week by week, of young insects or crawlers. The total number of insects collected on June 22 and June 29 was something over 1,500, one-third of which were so young that they were discarded for reasons noted below. In later collections the percentage of young ones decreased markedly until, on August 8, but few young crawlers were observed in the field. It will be observed by reference to Figure 1 that this period of maximum abundance of young insects is likewise the period in which the percentage of diseased specimens jumped from 18 to 64, and it is to be noted that following this sudden increase in mortality the young or crawler insects became less and less numerous.

In order to obtain definite data regarding the prevalence of the fungus at various periods during the season, so that its work might be measured with some accuracy, the following plan was adopted: Collections were made at approximately weekly intervals, an attempt being made to have them representative of the entire grove. The mealybugs were scraped by a penknife from the grapefruit or twigs to which they were attached and placed in ordinary pasteboard pill boxes. Preferably those grapefruit were chosen upon which large numbers of insects occurred, in order to facilitate the collection, but late in the season it became rather difficult conveniently to collect large numbers, as the colonies were decimated and the individuals scattered. In collecting the insects those dead and alive were scraped off indiscriminately, and when taken to the laboratory the crawlers or very small active members were discarded, and those infected with

the fungus were counted either that day or the day following. The remaining insects were then counted, placed in pill boxes with fresh grapefruit rind, and the boxes placed in a moist chamber. Dead specimens were removed daily and counted. They were removed, furthermore, before the fungus fruited, in order to eliminate the chances of new infections arising within the pill boxes from the dead

FIG. 2.—"Mealybugs on grapefruit following Bordeaux and oil emulsion for citrus scab. Mealybugs may be equally as abundant when Bordeaux and oil are not applied but such infestations are rather rare." Yothers. (Photograph by W. W. Yothers, 1920.)

specimens. After one week, which was considered ample time for all field infections to become evident, the experiments were closed. When, as occasionally occurred, a mealybug was collected in which Chrysoplatycerus was found, it was removed, but ignored in the count, the number of such specimens being too small to influence the total mortality either one way or the other.

The results of the various collections are diagrammed in Figure 1. It is believed that the progress and increasing rapidity with which the disease spread, as shown in this figure, may be regarded as a

reasonable and fairly accurate check on the activities of the fungus in the field. The table shows that of the first collection on June 13 only 11 per cent died of the disease, whereas in the last collection 94 per cent succumbed; and, furthermore, that the percentage of mortality jumped from 18 on June 22 to 64 on June 29, an increase of 46 per cent in one week's time. The rapidity with which such diseases spread when once established is remarkable, and it is strange that any insects escape alive.

Figure 1 records the events that occurred in one grapefruit grove. It is reasonable to believe, owing to the wide distribution of the fungus, that similar epidemics were present elsewhere, and that as a matter of fact such widespread destruction of the mealybug has been going on for years, unobserved and therefore unheeded by the citrus growers of the State.

RELATION OF FUNGICIDES TO MEALYBUGS.

From the standpoint of the citrus grower, which in fact is the true position for others who make recommendations to assume, insect and fungous enemies are lumped together in one category as injurious factors—factors which among other things tend to inhibit the health and growth of the trees and lower the marketability of the fruit. It is of no concern to the grower whether injury is caused by insects or diseases, except in so far as it is necessary for him to know the differences in order judiciously to apply remedial measures. He sees only the damage caused and translates it into dollars and cents. Unconsciously, perhaps, he mentally segregates these enemies—whether correctly or not is beside the point—into classes, according to the amount of damage or injury they have caused in the past when no artificial measures have been employed to control them. He has formed an opinion, for example, of the relative injury wrought by rust mites, white flies, melanose, scab, the purple scale, etc., and although this opinion may be erroneous, it will influence him in applying control measures. Although most growers would like to control all of their insect and fungous enemies, few attempt to do so. The majority are forced, for what they regard as economic reasons, to control the most injurious. If certain diseases seem to be causing great losses their control will be sought first, or if insect pests are particularly prevalent, these will first be the subject of control measures. In other words, if in the grower's opinion all of the citrus enemies can not be controlled economically, only those will be chosen for control that are causing the most injury. Such a procedure is natural and logical, as the object striven for is economic gain.

The artificial control of citrus diseases in Florida by fungicides and the natural control of injurious citrus insects by entomogenous

fungi are antagonistic, and in view of the effect of fungicides upon the latter, these facts should be kept in mind. It has been repeatedly shown, for example, that Bordeaux mixture, when employed to destroy the organisms causing citrus disease, at the same time destroys the entomogenous fungi; thus the natural balance that otherwise exists, imperfect though it may be at times, but upon which the grower, perhaps unconsciously, has relied, is upset to such a degree that great injury results from attacks by insect pests. Therefore a spray which may be of great importance as a control measure for citrus diseases becomes to a large degree of no commercial importance because the grower must choose either to control the diseases or to permit the natural agencies to control the insects. If he feels that the insects are more injurious than the diseases he will let the entomogenous fungi control the insects, especially since their work is performed at no expense whatever to him. The only alternative is to follow the fungicide with an insecticide, or it may be possible to apply the fungicide and insecticide in one mixture, but these are expensive processes that may prove to be unjustifiable economically.

With regard to the effect of fungicides upon the mealybug fungus, specific data are available in one instance. On August 11 and 12, 1921, a count was made of mealybugs in a grove in Orlando, a part of which had been sprayed with fungicides by the Bureau of Plant Industry, for the control of melanose, and a part of which had not been thus treated. Although some plats were sprayed with Bordeaux plus oil emulsion, some with copper soap, some with barium tetrasulphid, and some with lime-sulphur, for the present purposes all the sprayed trees will be lumped together in one category as "sprayed." While certain of the sprays employed contained an insecticide, the presence of the latter has been entirely disregarded because it has been repeatedly shown that such insecticides are relatively impotent in so far as mealybug control is concerned. In counting the mealybugs such arbitrary categories as "absent," "very scarce," "scarce," "abundant," "very abundant," and "has been very abundant" were employed: and, although crude, these will serve to show the relative degree of infestation. Within the last-named class were included those trees which showed evidences of a previous heavy infestation, but which at the time of the count were free from insects. The other terms are self-explanatory. There were 255 trees in the unsprayed area and 74 in the sprayed. Of the former, 4, or 1.6 per cent, were placed in the class "very abundant" and 6, or 2.4 per cent, in the class "has been very abundant." Of the sprayed trees 6, or 8.1 per cent, showed an infestation classed as very abundant, whereas 1, or 1.4 per cent, in a plat sprayed with lime-sulphur, showed evidences of having recovered from a past heavy infestation.

It is evident, therefore, that so far as mealybugs were concerned the trees in this grove were in better condition in the unsprayed areas than in the sprayed; in fact, there was 5.5 per cent more injury in the sprayed plats.

Observations on the prevalence of the mealybug fungus were made in connection with this count. A dead infected individual here and there in unsprayed areas showed that the fungus had been responsible for the destruction of the colonies included under the caption "has been very abundant." In those colonies classed as "very abundant" the fungus was very noticeable at the time the count was made. On the other hand, in the sprayed area, except for one tree sprayed with lime-sulphur, no fungus was observed, and there were no indications that it had been there previously. A few dead infected mealybugs, however, were found upon the tree sprayed with lime-sulphur.

In brief, this experiment shows that fungicides, with the possible exception of lime-sulphur, prevented the development of the mealybug fungus, which in turn permitted an unrestrained development of the mealybugs. In the grove where this experiment was performed the infestation was very scattered, as shown by the fact that of the 255 unsprayed trees, 185, or 72.5 per cent, were free from the insect.

Considered from the standpoint of a period of years, the mealybug is relatively innocuous as a citrus pest, and it is believed that its commercial control during such periods is brought about by the natural enemies, chiefly the fungous parasite herein described. Seasons obtain, however, such as the summer of 1921, and to a certain extent that of 1920, in which this insect appears in numbers sufficient to arouse the attention of the citrus grower. There seem to occur more or less lengthy periods in which control exists to all intents and purposes, alternating with periods of much shorter duration, lasting but one or two seasons, in which the insect threatens to become a serious pest. Numerical fluctuation of the mealybug is natural and unavoidable, for its control is largely brought about by natural enemies which are dependent for the perpetuation of their own species upon the presence of the hosts which they parasitize, the lack of which, particularly if the parasites are more or less specific, will cause them to disappear. It is very probable in the present instance that a great part of the fungus, which is extremely prevalent when the mealybugs are abundant, dies out for this reason, and in the period of recovery which follows, the host has the advantage and therefore increases in numbers until the parasite once again becomes sufficiently abundant to check it. The grower is concerned only with those periods in which the insect threatens to injure his fruit and trees. At such periods he can either resort to the employ-

ment of artificial methods or he can foster in several ways the development of the natural enemies. Unfortunately, however, no wholly successful artificial control measure is known. Suitable sprays have not been found in Florida. In certain instances a solid stream of water directed at high pressure against the mealybugs in order to knock them forcibly from the trees is advantageous. As the mealybugs' habit of clustering between adjacent grapefruit renders them somewhat inaccessible, however, such a spray must be applied several times for best results, and from the viewpoint of economy is not wholly satisfactory.

It should be remembered that the insect pest herein considered is one that becomes a nuisance periodically only, and that during many seasons it is unnecessary to employ any treatment to control it. The grower has learned that a few scattering colonies of mealybugs do not necessarily indicate that there is going to be a serious infestation, and that often the insects will not become abundant enough to justify spraying. For economic reasons, therefore, he will defer as long as possible the application of any control measure, hoping in the meanwhile that the mealybugs will disappear. Artificial measures are employed only when considerable injury has been wrought and when there are no apparent signs that it is going to cease. The observations of the past two years indicate that the fungous parasite will be invariably present at such times. Inasmuch as the known sprays, while of little value in themselves, actually tend to inhibit the disease in that diseased or dead individuals present at the time of spraying are dislodged, and thereby rendered impotent, while the healthy ones which the sprays do not dislodge or kill remain and reproduce unimpeded by the fungus, it is obvious that in rare instances only will it pay to employ artificial measures. On the other hand, the grower can aid appreciably in restoring the natural balance in his citrus grove by introducing the fungus from available sources as soon as possible in the spring. Unfortunately the organism has not yet been cultivated on artificial media. There is, however, a method by which large quantities of the fungus can be produced. Smith and Armitage[10] have shown that the citrus mealybug can be cheaply and successfully grown upon potato sprouts. With an abundance of insects it is a relatively simple matter to propagate the disease among them. The method employed is substantially the same as that used so successfully in growing large quantities of the brown-tail moth fungus, and consists briefly in obtaining a quantity of diseased insects and distributing them, while yet alive, in the field among the healthy ones. The success of this method depends upon getting the fungus established in the field early in the season. The State or Federal Government should

[10] Smith, Harry S., and Armitage, H. M. Op. cit., p. 121.

undertake the production of quantities of infected mealybugs for the use of the growers.

If, however, a grove has been sprayed for the control of citrus diseases, with Bordeaux mixture or other active fungicide which kills entomogenous as well as other fungi, the owner must be prepared for a heavy infestation of mealybugs, provided, of course, that these insects are present in the grove at the time the Bordeaux is applied. In such instances it would do no good to introduce the fungus and the application of artificial remedial measures might be advisable.

In California the Argentine and other ants are said[11] to be important factors in checking the work of the natural enemies, which in that State, so far as is known, are exclusively insect, or at least not fungus. It is said that they have been observed to carry living mealybugs—

> * * * to destroy and carry off the larvæ and eggs of natural enemies, to interfere with the free movement about the tree of certain beneficial insects, and by their constant attendance upon the mealybugs to prevent normal egg laying and feeding of adult parasites and predatory insects.

Ants have been frequently observed in Florida attending mealybug colonies, but no attempt has been made either to determine the different species involved or their relation to mealybugs, although they were frequently observed carrying these insects. It is difficult, however, to see how they can interfere in any way with the fungous parasite herein considered, unless they possess psychic powers of such a nature as to enable them to pick out for destruction the diseased but not dead specimens, for in carrying about dead sporulating specimens, or even in traveling about among such individuals, they would rather assist in spreading the fungus from insect to insect.

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[11] Woglum, R. S., and Neuls, J. D. Op. cit., p. 11.

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